MONITORING THE COASTAL OCEAN WITH THE GOES-R HYPERSPECTRAL ENVIRONMENTAL SUITE COASTAL WATERS IMAGER

Geostationary weather satellites, initiated in the late 1960s, have become a key part of the National Weather Service data stream used for operational weather forecasting. Today, the Geostationary Operational Environmental Satellites (GOES) continually observe the same area on the Earth to provide the near-continuous data that are critical to monitoring present conditions and providing input into weather forecast models. As these environmental satellites are continually being improved, we have an opportunity to develop a corresponding monitoring and modeling capability for the Nation's oceans. The National Oceanic and Atmospheric Administration (NOAA) is planning to include such a capability with the Hyperspectral Environmental Suite (HES) on the next generation GOES satellites, beginning with GOES-R, which is planned for launch in 2012.

The HES will be an instrument, or combination of instruments, that includes a capability for sounding the atmosphere and for imaging Coastal Waters (HES-CW). The HES-CW promises to revolutionize our understanding and management of U. S. coastal waters in the same way that the original GOES imaging has changed weather prediction over the last forty years. Much like the atmosphere, the coastal ocean is highly dynamic with strong currents driven by tides and winds. The current polar orbiting imagers can only provide ocean color images every day or two - too infrequent to characterize coastal variability. This coverage is further reduced by clouds and fog. However, with the increased frequency of sampling possible from a geostationary platform, we can sample when it is clear and frequently enough to see the major coastal events unfolding.

There is a growing concern about the health and future of the coastal ocean as expressed by the U.S. Commission on Ocean Policy in their report to Congress. In response Congress has already initiated an effort to establish an advanced Coastal Monitoring System and to improve coastal management practices to assure the future health of the coastal ocean for its many uses. The monitoring system includes the Integrated Ocean Observing System (IOOS) – the in-situ component, satellite remote sensing, and the development of advanced models of circulation and the transport of materials in the coastal ocean. A key part of that monitoring system is GOES-R HES-CW. HES-CW will provide the frequent imagery of the ocean surface that is needed to extend the in situ observations made by IOOS to the entire coastal zone. Additionally, HES-CW data will be essential for initiating and validating models of coastal ocean dynamics.

How Does A Geostationary Sensor Improve Our Ability to Monitor and Study the Coastal Ocean?

As planned, HES-CW will have significantly improved temporal, spatial and spectral sampling over existing and other planned satellites, which will greatly enhance our ability to monitor and assess the dynamics of the coastal ocean. The following sections discuss the advantages of these key improvements.

Improved Temporal Sampling

The addition of a capability to view coastal waters from a geostationary platform will provide the management and science community with a unique capability to observe the dynamic coastal ocean environment. Tides, diel winds (such as the land/sea breeze), river runoff, upwelling and storm winds drive coastal currents that can reach several knots. Furthermore, currents driven by diurnal and semi-diurnal tides reverse approximately every 6 hours. A minimum sampling frequency of three hours, as planned for HES-CW, is required to resolve these features, and to track water masses containing harmful algal blooms, oil spills or other features of concern for coastal environmental management that are driven by these currents.

Federal and state agencies are responsible for the management of fisheries, monitoring of water quality, protection of marine sanctuaries and marine mammal habitats, assessing the effects of storm events and other issues related to the use and protection of the coastal ocean. Each of these management responsibilities require an improved understanding of coastal ocean dynamics. Considerable progress has been made in our ability to monitor ocean color and temperature in the open ocean using the polar-orbiting satellites. However, the present once-a-day coverage from polar-orbiting satellites, which is further limited by clouds, is not sufficient to sample the dynamics of the coastal ocean. The geostationary platform with HES-CW will improve our ability to obtain usable imagery several times a day to resolve, among others, the effects of tides and wind events on coastal currents, and to understand changes in coastal water features that occur over a daily cycle. This capability will greatly improve our ability to manage coastal resources just as GOES imagery has improved our ability to monitor and forecast the weather.

Ocean color imaging requires sunlight and cloud free scenes. One advantage of geostationary imaging is the ability to wait until an area is cloud free, rather than sampling at one fixed time as set by the orbit for current polar orbiting ocean color imagers like SeaWiFS and MODIS. Plans for GOES-R include adaptive sampling to optimize cloud free imaging. For example, HES-CW imaging may be scheduled using the cloud maps from the Advanced Baseline Imager (ABI also on GOES-R) that images the entire U. S. and coastal waters every few minutes. The ABI is designed for cloud imaging, it has a limited set of bands and the gain is set to image clouds with the ocean as a black background. While it will not image ocean features it is ideal for queuing HES-CW which will have the appropriate bands and sensitivity for ocean imaging. This approach will maximize the collection of cloud free scenes from HES-CW.

The capability to obtain frequent cloud-free imagery will be an important asset to water quality monitoring because surface currents can alter phytoplankton and sediment distributions near the coast and because phytoplankton growth rates that approach a doubling per day can rapidly alter water quality. Monitoring of water quality parameters from satellite, particularly from coastal regions susceptible to harmful algal blooms, is improved by the capability to access imagery on any given day. Presently, ocean color images are used to estimate the size and extent of *Karenia brevis* blooms in the Gulf of

Mexico. For example, the Florida Fish and Wildlife Conservation Commission is responsible for monitoring hundreds of miles of coastline for this harmful algal bloom species, which causes neurotoxic shellfish poisoning. This monitoring information is used by the state agencies to adapt their sampling strategies to effectively and efficiently monitor beaches and shellfish harvesting areas. These agencies need access to up-to-date cloud-free imagery to design sampling strategies and plan field surveys. The frequent image acquisition available from a geostationary platform will improve the chances of obtaining a cloud-free image and allow imagery collected at different times of the day in a given region to be combined to generate daily cloud-free coastal ocean color scenes for the entire region.

Higher Spatial Resolution

the U. S. coastline is very complex with many sounds, bays and estuaries. In terms of area coverage the 300 m spatial resolution planned for HES-CW is approximately 10 times better than the approximately 1000 m resolution currently available from polar orbiting ocean color imagers (0.1 km^2 per pixel compared to 1 km^2). While the polar orbiting imagers can monitor the centers of only the very largest and widest estuaries in the country, the HES-CW can examine most of the small and tributary estuaries. This higher spatial resolution will provide a new capability for monitoring over 100 significant estuaries and provide sufficient information on complex areas like Chesapeake Bay, Puget Sound and the Florida Keys. The frequent imagery from HES-CW will significantly improve our ability to monitor water quality, large oil spills, harmful algal blooms and other issues that are critical to the management of these areas. The imagery will also aid the development of ecosystem models for these important areas. Applications will include the management of marine sanctuaries, providing harmful algal bloom and other health warnings and improved management of fisheries using the Essential Fish Habitat approach for key commercial and sport fish stocks.

Improved Spectral Resolution and Sensitivity

In addition to the increase in temporal resolution, another advantage of geostationary imaging is that the sensor can stare at an area of interest for extended periods of time. Thus it is possible to do high spectral resolution and high signal-to-noise imaging from geostationary platforms.

River runoff, suspended sediments, colored dissolved organic matter, large phytoplankton blooms and bottom reflectance in shallow water all add to the complexity of the optical signal in coastal waters. Current sensors do not measure the light in enough different wavelengths to permit separating these materials. However, obtaining many wavelengths requires more signal. The HES-CW, by staring, can detect more light at any wavelength. Because there is sufficient signal, the spectra may be divided into more channels increasing the ability to resolve coastal features. While the threshold requirement is that HES-CW is a multispectral instrument with 14 spectral bands, a key goal is that it be a hyperspectral instrument. Experience with airborne systems and Hyperion on NASA's

EO-1 spacecraft has shown that the continuous spectra obtained with a hyperspectral instrument can greatly improve our ability to resolve the complexity of the coastal ocean.

Developing Future Applications

HES-CW is primarily an operational instrument designed to meet the needs of NOAA and other agencies responsible for the management of coastal resources. However, the HES-CW capabilities make it possible to address new scientific questions which could lead to future operational capabilities. For example, beyond the physical mixing by winds and tides, the biology of phytoplankton is also changing on an hourly basis. Phytoplankton typically have a daily cycle of photosynthesis and cell division. With HES-CW we will be able to measure changes and the dynamics of phytoplankton chlorophyll concentration and chlorophyll fluorescence over the day. This changing ratio will give new insight into the health and productivity of coastal oceans.

The vertical migration of some key harmful algal bloom species like *Karenia brevis* is another important biological light driven cycle. Frequent sampling with HES-CW will allow us to characterize this cycle which may be valuable for identifying and tracking harmful algal blooms. If there is no visible bloom at 10 AM, and then high levels of sea surface chlorophyll are observed at 1 PM, this will likely indicate that we are observing a bloom of a vertically migrating species in these waters. This approach will be potentially very useful for Florida and California where the common harmful algal bloom species migrate vertically. The information on vertical migration is also a critical input into models that are being developed to track harmful algal blooms.

HES-CW instruments will be included in the long term GOES series beginning with GOES-R. This long term data record can be used to quantify inter-annual to decadal changes in coastal flow patterns, ecosystem dynamics, and organic matter transfer across land-air-sea interfaces. This will require the development of climate quality data records. The use of HES-CW data for this application requires well calibrated data, a very stable sensor and the processing and archiving of climate data records. This data set will be extremely valuable for assessing the effects of global climate change on the U. S. coastal environment.

Finally, the long term goal is the development of now-cast and forecast models for the coastal ocean. Just as weather satellite data has been essential for developing today's weather models HES-CW data and in-water data from the IOOS will be essential for the development of coastal ocean models. HES-CW data will be essential for initiation and validation of models for coastal water quality and phytoplankton biomass and productivity.

What is Happening Now?

Industry is now involved in the process of designing the HES. The HES is any instrument or combination of instruments that meet the following threshold tasks: two atmospheric sounding tasks, which include Disk Sounding (DS) and Severe Weather/Mesoscale sounding (SW/M), and a shelf and coastal waters imaging task (CW). Based on competitive bid proposals, three companies (BAE, ITT and Ball Aerospace) were selected in June 2004 to do two-year initial design and risk reduction studies for HES. During the first year, the contractors will look more at requirements and assess options/trade-offs for implementation. During the second year they will concentrate more on developing their design to build HES. As in any spacecraft system there will be strong competition between instruments for space, weight, power and other resources on the spacecraft. It is important to monitor this process and assure that the HES-CW requirements will be met by the proposed designs.

To assure that ocean applications and science requirements are met NOAA has established the Coastal Ocean Applications and Science Team (COAST) to establish consensus scientific oversight of this process. The immediate task for COAST is to review the nominal coastal ocean threshold and goal requirements being used as the basis for the HES studies. It will be important to clearly articulate the applications, particularly those that are operational, and how each is dependent on specific requirements. If there are to be recommended changes to the nominal requirements, the contractors will need to know those recommendations by January 2005. Following this initial effort COAST will be merged into the GOES-R Risk Reduction Program in 2006. The COAST role within the GOES-R Risk Reduction Program will be to lead the effort to guarantee that the HES-CW data can be effectively used for coastal ocean applications and science. The purpose of the GOES-R Risk Reduction Program is to prepare for the evaluation of the ABI, HES, HES-CW radiances, to develop advanced products, and to assess the utility of the improved measurement capabilities in NESDIS, NWS, NOS and other NOAA Line Office operations. These efforts will demonstrate the GOES-R capabilities to both public and private sector users in an efficient, effective and timely manner. It will pave the way for a subsequent smooth operational implementation.

Future Returns

There is a growing concern about the health and future of the coastal ocean as expressed by the U.S. Commission on Ocean Policy in their report to Congress. Congress has already initiated the effort to establish an advanced Coastal Monitoring System and to improve coastal management practices to assure the future health of the coastal ocean for its many uses. HES-CW will provide critical data for that monitoring effort. HES-CW will provide the frequent views of the ocean surface that is needed to extend the in situ observations made by IOOS. Additionally, HES-CW data will be essential for initiating and validating models of coastal ocean dynamics.

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